National Aeronautics and Space Administration Goddard Earth Science Data Information and Services Center (GES DISC)

README Document for Suomi-NPP OMPS NM Sulfur Dioxide (SO_2) L2 Product

Version 2.0

Last Revised 05/10/2017

Goddard Earth Sciences Data and Information Services Center (GES DISC)
http://disc.gsfc.nasa.gov
NASA Goddard Space Flight Center
Code 610.2
Greenbelt, MD 20771 USA

Prepared By:

Your Name | *Kai Yang*

Name
GES DISC
GSFC Code 610.2
Date

Date

Name
University of Maryland

Reviewed By:

Reviewer Name | Date

Reviewer Name
GES DISC
GSFC Code 613.2

Date

Goddard Space Flight Center
Greenbelt, Maryland

Revision History

Revision Date	*Changes*	*Author*
05/10/2017	First Release	Kai Yang

Table of Contents

Contents

1.0 Introduction

This document provides basic information for using the Suomi National Polar-orbiting Partnership (NPP) Ozone Mapping and Profiling Suite (OMPS) Nadir Mapper (NM) Sulfur Dioxide (SO_2) Level 2 (L2) orbital products, or OMPS_NPP_NMSO2_L2 (NMSO2-L2) for short. The NMSO2-L2 product consists of measurements of atmospheric SO_2 abundance, namely the SO_2 vertical column amount, and other geophysical parameters that characterize the measurement conditions.

1.1 OMPS Instrument Description

The Ozone Mapping and Profiling Suite (OMPS) is designed to measure the global distribution of total column ozone on a daily basis, as well as the vertical distribution of ozone in the stratosphere and lower mesosphere (~15 – 60 km).

Nadir Mapper (NM) – The NM is designed primary for mapping global total column ozone distribution from its measurements of backscattered ultraviolet (BUV) spectra between 300 – 380 nm.

Nadir Profiler (NP) – The NP is designed for monitoring stratospheric ozone profiles, retrieved from the measured backscattered UV spectra between 250 – 310 nm.

Limb Profiler (LP) – The LP measures limb scattered radiation in the UV, visible, and near-infrared (NIR) spectral regions, from which ozone density and aerosol extinction coefficient profiles are estimated in altitude range between the lower stratosphere (10 – 15 km) and the upper stratosphere (55 km).

OMPS NM observations and its sulfur dioxide (SO_2) measurements will be described here.

1.1.1 OMPS NM

The OMPS-NM is a nadir-viewing hyperspectral instrument measures BUV radiance spectra, covering the 300–380 nm wavelength range with a spectral resolution of ~1 nm and a sampling rate of ~0.42 nm per pixel. Suomi NPP is in a Sun-synchronous orbit with a local ascending (northbound) equator crossing time at 1:30 PM. The OMPS-NM provides contiguous daily global coverage in about fourteen (14) orbits using a two-dimensional charge-coupled device (CCD) that scans a 2800 km cross-track swath (110° field of view), divided into 35 instantaneous fields of views (IFOVs) or pixels, which have a ground footprint size of 50 km × 50 km at nadir. One orbit of OMPS-NM observations contains about 400 cross-track viewing lines, each scanning ~7.5 seconds along track, from southern to northern terminator on the sunlit side of the Earth. While the OMPS-NM is designed primarily to measure global total ozone (O_3), other geophysical quantities, such as trace gas (SO_2 and NO_2) abundances and the cloud optical centroid pressure (OCP) [*Vasilkov et al*, 2014], may be derived from the hyperspectral measurements of OMPS-NM. More comprehensive descriptions of the OMPS-NM instrument and its performance are given in *Seftor et al* [2014] and *Flynn et al* [2014].

1.2 Algorithm Background

The Direct Vertical Colum Fitting (DVCF) algorithm [*Yang et al*, 2013] is applied to the OMPS-NM spectral measurements to retrieve the atmospheric SO_2 vertical columns. The DVCF algorithm was called the Iterative Spectral Fitting (ISF) algorithm, when it was first developed [*Yang et al,* 2009a] for simultaneous O_3 and SO_2 retrieval from the observations of Ozone Monitoring Instrument (OMI) flying on the Aura spacecraft. Since then, a number of advancements have been developed to improve the accuracy of O_3/SO_2 quantification, and to measure additional geophysical parameters, including SO_2 plume height [*Yang et al*, 2009b, 2010], effective cloud pressure [*Yang et al*, 2013], and nitrogen dioxide (NO_2) vertical column [*Yang et al,* 2014].

The retrieval approach of DVCF algorithm determines trace gas vertical columns and other geophysical parameters by adjusting them iteratively until the difference between the satellite-measured Earth view radiance spectra and those simulated using an accurate radiative transfer model is minimized. Algebraically, the DVCF algorithm equation for a wavelength (λ) is expressed as

$$\ln I_m - \ln I_{TOA} = \sum_{p=1}^{N_p} \Delta X_p \left.\frac{\partial \ln I_{TOA}}{\partial X_p}\right|_{X_p = X_{Pi}} + \left(\sum_{k=0}^{N_R} \Delta R_k (\lambda - \lambda_{ref})^k \right) \left.\frac{\partial \ln I_{TOA}}{\partial R_0}\right|_{R_0 = R_{0_i}} + \varepsilon, \qquad (1)$$

where I_m is the measured reflectance spectrum (i.e., the ratio of the NM measured radiance to the NM measured irradiance), and I_{TOA} is the calculated reflectance at the i^{th} iteration based on a forward model, and ε is the total error, including both satellite measurement error and the forward modeling uncertainty. The forward model used in DVCF algorithm is the TOMRAD model [*Dave*, 1965] with added contributions from rotational Raman scattering (RRS) calculated using the LIDORT-RRS code [*Spurr et al*., 2008], to provide highly accurate modeling of radiative transfer in Rayleigh atmosphere with molecular absorptions only.

Starting with an initial guess of state vector $\{X_p,\ p = 1 \ldots N_p\}$, the OCP and the reflectivity parameters $\{R_k,\ k = 0 \ldots N_R\}$, which specify the Mixed Lambert-Equivalent Reflectivity (MLER) model, are determined using reflectance measurements in the longer wavelength region (333 – 345 nm, weak O_3 and SO_2 absorptions). Next the set of linear equations (1) for each wavelength in the fitting window (308 – 333 nm, strong O_3 and SO_2 absorptions) can be solved by least squares fitting of residuals ($\ln I_m - \ln I_{TOA}$) to the weighting functions {$\partial \ln I_{TOA} / \partial X_p$, p = 1…$N_p$} and obtain state vector adjustment {ΔX_p, p = 1…N_p}, and the linearization point for the next iteration {$X_p = X_p + \Delta X_p$, p = 1…N_p}. The weighting functions are re-computed with the updated state vector at each iterative step to eliminate the nonlinear gas absorption effect that often leads to SO_2 under estimation [*Yang et al*, 2009a]. The final solution of state vector {X_p, p=1…Np} is achieved when the iteration converges, i.e., the changes {ΔX_p, p=1…Np} in state vector between successive iterations are below certain thresholds.

The initial state vector for O_3 is taken from the O_3 profile climatology of McPeters and Labow [2012], and the SO_2 initial state vector is selected from a number of prescribed vertical profiles, including the SO_2 monthly mean profiles constructed from a full year GEOS-Chem run with 2012 meteorology and emission [*Yang et al*, 2014], and four (4) vertically localized distributions: lower tropospheric (TRL) profile centered at 2.5 km, middle tropospheric (TRM) profile centered at 7.5 km, upper tropospheric (TRU) profile centered at 11.0 km, and lower stratospheric (STL) profile centered at 16.0 km. Note that this localized distribution is specified by a generalized distribution function [*Yang et al*, 2010] with a 2 km width.

Ozone strongly absorbs UV radiation in the spectral range used in SO_2 retrieval, therefore an accurate retrieval of SO_2 requires accurate information about O_3 vertical distribution. Especially it needs an accurate quantification of stratospheric O_3 profile, which locates above most anthropogenic and volcanic SO_2 plumes, thus significantly affects the amount of UV photons available for SO_2 absorption. The DVCF algorithm retrieves the O_3 profile by including in the adjustable state vector the most likely profile deviations from the climatological (mean) O_3 profile. These likely O_3 profile adjustments are represented by the Eigen modes of O_3 profile covariance matrices, constructed monthly for each 10° latitude bands from Aura Microwave Limb Sounder (MLS) and balloon sondes O_3 profile data. Typically including three (3) to five (5) Eigen modes in the iterative fitting is sufficient to account for the O_3 profile effect on SO_2 quantification.

Clouds and aerosols are frequently co-located with SO_2, especially in satellite observations of volcanic plumes and air pollution episodes. The presence of aerosols/clouds changes the photon contributions to the satellite measured UV radiation compared to the Rayleigh atmosphere. To account for the combined effects of surface reflection and atmospheric scattering without explicitly including clouds/aerosols in the forward model computation, the DVCF approach derives the albedo and the pressure of the underlying boundary in cloud-free and fully cloud-covered IFOVs, or the cloud fraction and effective cloud pressure for the partially cloudy IFOV, including the spectral variation of the albedo or cloud fraction in the longer wavelength region. They are then extrapolated to the shorter wavelength window (i.e., spectral region with strong O_3 and SO_2 absorptions) based on the N_R order polynomial of λ-λ_{ref} (see equation 1). The DVCF algorithm derives the MLER parameters self consistently with the reflectance measurements, i.e., forward modeling with the derived MLER parameters closely reproduces the measured reflectance spectrum in the full fitting spectral range. Doing so simulates the light path distributions closely to provide a proper treatment of measurement sensitivity effects. For instance, they are incorporated in the DVCF weighting functions calculation to account for the sensitivity reduction due to the partial shielding of trace gases located below the scattering particles, as well as sensitivity enhancement for trace gases located at higher altitudes.

Note that the first order coefficient (R_1, left hand side, second term of equation 1) of the derived MLER parameters is a useful quantity to characterize the observing condition, because R_1 may be used as an Aerosol Index (AI): a positive AI indicates the presence of UV absorbing aerosols, even with underlying clouds, while a negative AI signifies the absence of absorbing aerosols and the likely presence of non-absorbing aerosols (like sulfate) and/or clouds.

1.3 Data Disclaimer

NMSO2-L2 product contains a data field PixelQuality, which is equal to 0 or -1 for each IFOV to indicate valid retrieval or bad data. We recommend discarding IFOVs with PixelQuality equal to -1.

Processing is skipped when solar zenith angle is greater than or equal to 88° or viewing zenith angle greater than 70°. For these IFOVs, the PixelQuality set to -1 and the corresponding retrieved data fields: O_3, SO_2, OCP, and reflectivity parameters, are set to fill values.

Successful retrievals are usually achieved for nearly all the IFOVs within the angular ranges specified above. However the DVCF retrievals may fail for a very tiny fraction of the IFOVs, mostly due to artifacts contained in the measured reflectance spectra, such as negative radiances or inconsistent values among different spectral regions. The PixelQuality is set to -1 for a failed retrieval.

Like other hyper-spectral UV instruments, OMPS-NM spectral measurements often contain 'spectral spikes', i.e., unusually high or low radiance values with deviations (from the mean of adjacent pixles) that exceed the radiance measurement noise levels of the instrument. NMSO2-L2 processing includes spike detection and excludes detected spike pixels in the fitting of measured spectra. This detection works nearly perfectly for isolated spikes, but is less effective when multiple adjacent spectral pixels are spiked simultaneously, as in the case when the CCDs are bombarded by energetic charged particles in the South Atlantic Anomaly (SAA) region, which is roughly bounded by the lat-lon box: -50° < latitude < 0° and -20° < longitude < -90°. Inside the SAA region, the retrieved SO_2 columns tend to have much higher noise level than those outside the region.

Large uncertainties are typically associated with retrieval of SO_2 in the Planetary Boundary Layer (PBL), primary due to two factors: 1) mismatch between prescribed SO_2 profile (which is taken from GEOS-chem monthly climatology) and the actual SO_2 vertical distribution, 2) the frequent presence of aerosols and/or clouds in the IFOV. To facilitate assessment of PBL retrieval, an additional data field, with the ABV (short for above) suffix, is included in the NMSO2-L2 product file. Instead of using the MLER model, the ABV retrieval uses the LER model to describe the lower boundary of an IFOV: the scene pressure, albedo, and its spectral dependence are determined in the long wavelength (weak O_3 and SO_2 absorption) region, and then extrapolated to the short wavelength (strong O_3 and SO_2 absorption) region for O_3/SO_2 retrieval. The retrieved ABV SO_2 column represents the amount of integrated SO_2 vertical profile (taken from GEOS-chem climatology) above the LER surface. Since the LER surface pressure is lower than or equal to the pressure at the terrain or sea surface, the SO_2 column shielded by aerosols/clouds is not included in this above (ABV) surface retrieval. Thus the ABV SO_2 column is the lower bound of the PBL SO_2. An elevated ABV SO_2 value is a reliable indicator for the presence of SO_2 in the IFOV. In the case that a PBL value is much higher than the corresponding ABV value, the associated PBL SO_2 uncertainty is increased significantly, because the shielded (inferred) SO_2 contributes a larger fraction to the PBL total.

2.0 Data Organization

These data contain SO_2 and the associated information retrieved from OMPS-NM spectral measurements using the DVCF algorithm. The NMSO2-L2 app processes the OMPS-NM Level 1B (L1B) data and generates the Level 2 (L2) product file: one orbit of L1B data yields one L2 data granule, which covers the sunlit portion of the orbit with an approximately 2800 km wide swath. During the normal mode of operation, each swath contains approximately 400 viewing or scan lines along the ground track of the satellite, with each scan line containing 36 pixels or IFOVs across the satellite track. Note that instead of the 35 (typically described for the OMPS-NM) cross-track pixels, 36 cross-track pixels are contained in the OMPS-NM L1B data, due to the L1B processing in the NASA Ozone SIPS retains the two central (near-nadir) IFOVs (30 km × 50 km and 20 km × 50 km), without aggregating them into the nominal 50 km x 50 km pixel. Suomi NPP's orbit period is ~101 minutes, yields 14 or 15 granules per day, providing fully contiguous coverage of the globe during normal mode operation. The data stored in a L2 granule file are ordered in time sequence.

2.1 File Naming Convention

The OMPS-NM data products uses the following file name convention:
OMPS-satellite_shortname-**L**level _observationTime_**o**oribtnumber_productionTime.**h5**

Where:

- satellite = NPP
- shortname = NMSO2
- level = 2
- observationTime = start date and time of measurements in *yyyy***m***mmdd***t***hhmmss* format
    - *yyyy* = 4-digit year number[2012-current]
    - *mm* = 2-digit month number [01-12]
    - *dd* = 2-digit day number [01-31]
    - *hhmmss* = observation time [UTC time]
- orbitnumber = 5-digit orbit number
- productionTime = file creation stamp in *yyyy***m***mmdd***t***hhmmss* format
    - *yyyy* = 4-digit year number[2012-current]
    - *mm* = 2-digit month number [01-12]
    - *dd* = 2-digit day number [01-31]
    - *hhmmss* = production time [local time]

Filename example:

OMPS-NPP_NMSO2-L2_2015m0424t170310_o18080_2017m0419t202137.h5

2.2 File Format and Structure

NMSO2-L2 data files are provided in the HDF5 format (Hierarchical Data Format Version 5), developed at the National Center for Supercomputing Applications http://www.hdfgroup.org/. These files use the Swath data structure format, with two primary groups: GeolocationData and ScienceData. Section 3.0 describes the dimensions, global attributes, and data fields in more detail.

2.3 Key Science Data Fields

The data fields most likely to be used by typical users of the NMSO2-L2 product are listed in this section. Important information about data temporal coverage and data quality is also provided.

Parameter	Group
Latitude	GeolocationData
Longitude	GeolocationData
ColumnAmountSO2_PBL	ScienceData
ColumnAmountSO2_ABV	ScienceData
ColumnAmountSO2_TRL	ScienceData
ColumnAmountSO2_TRM	ScienceData
ColumnAmountSO2_TRU	ScienceData
ColumnAmountSO2_STL	ScienceData
RadiativeCloudFraction	ScienceData
PixelQualityFlags	ScienceData

2.3.1 Data Temporal Coverage

The first OMPS-NM measurements used to create the NMSO2-L2 product were taken on January 28, 2012. OMPS-NM data for February-March 2012 have numerous gaps due to variations in instrument operations and changes in sample tables. Regular operations began on April 2, 2012. OMPS-NM performed high spatial resolution observations about one day per week from April 2012 to June 2016. These high-resolution data have reduced spectral coverage, and they are not processed with the current version of NMSO2-L2 app.

2.3.2 Data Quality

Fill values are inserted into data fields in ScienceData group for the IFOVs with solar zenith angle (SZA) >= 88° or with viewing zenith angle (VZA) > 70°. Fill values are also set for these data fields of IFOVs with processing error, which is rarely encountered for OMPS-NM data. In short, successful retrieval is usually achieved for nearly all the OMPS-NM observations that fall within the valid angular range.

ColumnAmountSO2_PBL data with SZA > ~80° may not be useful, as the measurement sensitivity to SO_2 in the PBL is greatly reduced for high SZA observations. The ColumnAmountSO2_TRM, ColumnAmountSO2_TRU, and ColumnAmountSO2_STL may contain valid information for SZA up to ~84°.

All the ColumnAmountSO2 data fields may contain negative values due to random noise in the measured radiance spectra. Negative SO_2 columns are valid data, and excluding them in spatial or temporal averages would introduce positive biases in the means.

3.0 Data Contents

3.1 Dimensions

The NMSO2-L2 product includes the following dimension terms:

Name	long_name	Value
DimAlongTrack	Along-track dimension	400
DimCrossTrack	Cross-track dimension	36
DimCorners	IFOV corner dimension	4

3.2 Global Attributes

Metadata in the NMSO2-L2 product data files includes attributes whose value is constant for all files and attributes whose value is unique to each individual file. Table 3.2.1 summarizes these global attributes.

3.2.1 Global Attributes Table

Global Attribute	Type	Description
DATA_QUALITY	Integer16	Granule level flag: 0=some good data, 1= no good data
DOI	String	DOI value
DayNightFlag	String	Identify day or night measurements
EquatorCrossingDate	String	Equator crossing date
EquatorCrossingLongitude	Float32	Equator crossing longitude
EquatorCrossingTime	String	Equator crossing time

Format	String	Data file format
LocalGranuleID	String	File name
LongName	String	Full product name
OrbitNumber	Integer32	Orbit number
PGEVersion	String	Software version
ProductDateTime	String	Time of file creation
RangeBeginningDateTime	String	Starting date and time of data
RangeEndingDateTime	String	Ending date and time of data
ShortName	String	Short product name
TAI93At0zOfGranule	Real64	TAI time at 00:00 UTC at date of start of granule
VersionID	String	Version ID for this product
VersionNumber	String	Version number for this product
acknowledgement	String	Acknowledgement of data producer
comment	String	Any additional comments
contributor_name	String	Name of data creator
contributor_role	String	Role of data creator
creator_email	String	e-mail address of data creator
creator_institution	String	Organization of data creator
creator_name	String	Name of data creator
creator_type	String	Type of data creator (e.g. person, organization)
date_created	String	Date of file creation
history	String	History of file
id	String	Short product name
institution	String	Producer of data
keywords	String	Identifying keywords
keywords_vocabulary	String	Source of keywords used in metadata

license	String	Source of data information regulations
metadata link	String	Web address for metadata DOI
processing_level	String	Level of data product (e.g. L1B, L2)
publisher_email	String	e-mail address of data publisher
publisher_institution	String	Organization of data publisher
publisher_name	String	Name of data publisher
publisher_type	String	Organization type of data publisher
publisher_url	String	URL of data publisher
references	String	Reference material for data product
source	String	Source of measurement data
summary	String	Any additional summary
time_coverage_end	String	Ending data and time of data
time_coverage_start	String	Starting date and time of data
title	String	Title of data product

3.3 Products/Parameters

3.3.1 Level 2 Data Fields in GeolocationData Group

Data Field Name	Description	Units	Dimension
GroundPixelQualityFlags	Ground Pixel Quality Flag	No Units	DimAlongTrack, DimCrossTrack
ImageMidpoint_TAI93	TAI93 Image Midpoint Time	seconds	DimAlongTrack
InstrumentQualityFlags	Swath Level Geolocation Quality Flags	No Units	DimAlongTrack
Latitude	Geodetic Latitude of IFOV center	degrees_North	DimAlongTrack, DimCrossTrack
LatitudeCorner	Geodetic Latitude of IFOV Corner Points	degrees_North	DimAlongTrack, DimCrossTrack, DimConers
Longitude	Geodetic Longitude of IFOV center	degrees_East	DimAlongTrack, DimCrossTrack
LongitudeCorner	Geodetic Longitude of IFOV Corner Points	degrees_East	DimAlongTrack, DimCrossTrack, DimConers
RelativeAzimuthAngle	Relative Azimuth Angle	degrees	DimAlongTrack, DimCrossTrack

SolarAzimuthAngle	Solar Azimuth Angle	degrees	DimAlongTrack, DimCrossTrack
SolarZenithAngle	Solar Zenith Angle	degrees	DimAlongTrack, DimCrossTrack
SpacecraftAltitude	Spacecraft Altitude	m	DimAlongTrack
SpacecraftLatitude	Spacecraft Latitude	degrees_North	DimAlongTrack
SpacecraftLongitude	Spacecraft Longitude	degrees_East	DimAlongTrack
SpacecraftSolarZenith	Sub Satellite Solar Zenith Angle	degrees	DimAlongTrack
UTC_CCSDA_A	UTC Image Midpoint Time, a twenty-seven character UTC date-and-time string	No Units	(DimAlongTrack)
ViewingAzimuthAngle	Viewing Azimuth Angle	degrees	DimAlongTrack, DimCrossTrack
ViewingZenithAngle	Viewing Zenith Angle	degrees	DimAlongTrack, DimCrossTrack

NOTE: ***Data fields in the GeolocationData Group are copied from the input L1B file.***

GroundPixelQualityFlag. Bit-packed definition table:

0-7	Unused		
8	Eclipse Flag	WARNING	Indicates ground pixel is within umbra or penumbra of the moon
9-15	Unused		

InstrumentQualityFlags. Bit-packed definition table:

0-3	Unused		
4-5	SAA Flag	WARNING	Indicates location of spacecraft w.r.t. SAA 0 = outside SAA boundaries 1 = <5% of nominal maximum SAA effect 2= between 5% and 40% of nominal maximum SAA effect 3 = >40% of nominal maximum SAA effect
6-19	Unused		
20	Maneuver Flag	WARNING	Indicates a spacecraft attitude maneuver was in progress during the measurement
21	Attitude Threshold Flag	WARNING	Indicates any of the 3 geodetic spacecraft attitude Euler angles exceeds a defined threshold
22-31	Unused		

ImageMidpoint_TAI93. The time in seconds since 1993-01-01 00:00:00 at the mid-point of a scan line

Latitude. Geodetic Latitude of the IFOV center

LatitudeCorner. Geodetic Latitude of the IFOV corners, CCW relative to flight direction: LL,LR,UR,UL

Longitude. Geodetic Longitude of the IFOV center

LongitudeCorner. Geodetic Longitude of the IFOV corners, CCW relative to flight direction: LL,LR,UR,UL

RelativeAzimuthAngle. The relative azimuth angle at the center of the IFOV, it is equal to (SolarAzimuthAngle+180°−ViewingAzimuthAngle)

SolarAzimuthAngle. The solar azimuth angle at the center of the IFOV

SolarZenithAngle. The solar zenith angle at the center of the IFOV

SpacecraftAltitude. Spacecraft altitude above the Earth surface

SpacecraftLatitude. Geodetic latitude at the sub-point of spacecraft

SpacecraftLongitude. Geodetic longitude at the sub-point of spacecraft

SpacecraftSolarZenith. The solar zenith angle at the sub-point of spacecraft

UTC_CCSDA_A. A twenty-seven character UTC date-and-time string, representing the UTC time at the mid-point of a scan line

ViewingAzimuthAngle. The viewing azimuth angle at the center of the IFOV

ViewingZenithAngle. The viewing zenith angle at the center of the IFOV

3.3.2 Level 2 Data Fields in ScienceData Group

Data Field Name	Description	Units	Dimension
AerosolIndex	UV Aerosol Index	1	DimAlongTrack, DimCrossTrack
CloudFraction	Cloud Fraction	1	DimAlongTrack, DimCrossTrack
CloudPressure	Effective Cloud Pressure	hPa	DimAlongTrack, DimCrossTrack
CloudRefletivity	Cloud Reflectivity	1	DimAlongTrack, DimCrossTrack
ColumnAmountO3isf	O3 DVCF Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
ColumnAmountO3pair	TOMS-like O3 Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
ColumnAmountSO2_ABV	SO_2 ABV Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
ColumnAmountSO2_PBL	SO_2 PBL Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack

ColumnAmountSO2_STL	SO_2 STL Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
ColumnAmountSO2_TRL	SO_2 TRL Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
ColumnAmountSO2_TRM	SO_2 TRM Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
ColumnAmountSO2_TRU	SO_2 TRU Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
GroundRefletivity	Ground Reflectivity	1	DimAlongTrack, DimCrossTrack
PixelQualityFlags	Pixel Quality Flags	No Units	DimAlongTrack, DimCrossTrack
RadiativeCloudFraction	Radiative Cloud Fraction	1	DimAlongTrack, DimCrossTrack
ScenePressure	Effective Scene Pressure	hPa	DimAlongTrack, DimCrossTrack
SceneRefletivity	Lambertian Equivalent Reflectivity	1	DimAlongTrack, DimCrossTrack
SlantColumnAmountSO2	SO_2 Slant Column Amount	DU	DimAlongTrack, DimCrossTrack
TerrainPressure	Terrain Pressure	hPa	DimAlongTrack, DimCrossTrack

<u>AerosolIndex</u>. UV Aerosol Index determined from spectral slope of the reflectivity based on the retrieved MLER parameters

<u>CloudFraction</u>. MLER cloud fraction

<u>CloudPressure</u>. Pressure for the MLER cloud surface

<u>CloudRefletivity</u>. Albedo for the MLER cloud surface

<u>ColumnAmountO3isf</u>. Total vertical column amount O_3 retrieved using the iterative spectral fitting algorithm

<u>ColumnAmountO3pair</u>. Total vertical column amount O_3 retrieved using radiance measurements at a pair of wavelengths: 317.5 nm and 333.0 nm

<u>ColumnAmountSO2_ABV</u>. Total vertical SO_2 column amount above the scene pressure retrieved assuming SO_2 vertical distribution specified by the GEOS-chem climatological profile.

<u>ColumnAmountSO2_PBL.</u> Total vertical SO_2 column amount above the terrain or sea surface retrieved assuming SO_2 vertical distribution specified by the GEOS-chem climatological profile.

<u>ColumnAmountSO2_TRL.</u> Total vertical SO_2 column amount, retrieved with a prescribed Lower TRopospheric (TRL) profile centered at 2.5 km above surface.

ColumnAmountSO2_TRM. Total vertical SO_2 column amount, retrieved with a prescribed Middle TRopospheric (TRM) profile centered at 7.5 km above surface.

ColumnAmountSO2_TRU. Total vertical SO_2 column amount, retrieved with a prescribed Upper TRopospheric (TRU) profile centered at 11.0 km above surface.

ColumnAmountSO2_STL. Total vertical SO_2 column amount, retrieved with a prescribed Lower STratospheric (STL) profile centered at 16.0 km above surface.

GroundRefletivity. Albedo of the MLER terrain or sea surface.

PixelQualityFlags. Pixel Quality Flags contains 2 values with the following definition:

0 = Good_Pixel

-1 = Bad_Pixel

RadiativeCloudFraction. Radiative cloud fraction - the fraction of measured radiance contributed from clouds/aerosols within the IFOV.

ScenePressure. Effective Scene Pressure of the IFOV

SceneRefletivity. Lambertian Equivalent Reflectivity of the IFOV

SlantColumnAmountSO2. SO_2 Slant Column Amount

TerrainPressure. Pressure for the MLER terrain or sea surface

4.0 Options for Reading the Data

There are many tools and visualization packages (free and commercial) for viewing and dumping the contents of HDF5 files. Libraries are available in several programming languages for writing software to read HDF5 files. A few simple to use command-line and visualization tools, as well as programming languages for reading the L2 HDF5 data files are listed in the sections below. For a comprehensive list of HDF5 tools and software, please see the HDF Group's web page at http://www.hdfgroup.org/products/hdf5_tools/.

4.1 Command Line Utilities

4.1.1 h5dump (free)

The h5dump tool, developed by the HDFGroup, enables users to examine the contents of an HDF5 file and dump those contents, in human readable form, to an ASCII file, or alternatively to an XML file or binary output. It can display the contents of the entire HDF5 file or selected objects, which can be groups, datasets, a subset of a dataset, links, attributes, or datatypes. The h5dump tool is included as part of the HDF5 library, or separately as a stand-alone binary tool:

http://www.hdfgroup.org/HDF5/release/obtain5.html

4.1.2 ncdump (free)

The ncdump tool, developed by Unidata, will print the contents of a netCDF or compatible file to standard out as CDL text (ASCII) format. The tool may also be used as a simple browser, to display the dimension names and lengths; variable names, types, and shapes; attribute names and values; and optionally, the values of data for all variables or selected variables. To view HDF5 data files, version 4.1 or higher is required. The ncdump tool is included with the netCDF library. **NOTE: you must include HDF5 support during build.**

http://www.unidata.ucar.edu/downloads/netcdf/

4.1.3 H5_PARSE (IDL/commercial)

The H5_PARSE function recursively descends through an HDF5 file or group and creates an IDL structure containing object information and data values. You must purchase an IDL package, version 8 or higher, to read the L2 HDF5 data files.

http://www.harrisgeospatial.com/ProductsandSolutions/GeospatialProducts/IDL.aspx

4.2 Visualization Tools

4.2.1 HDFView (free)

HDFView, developed by the HDFGroup, is a Java-based graphic utility designed for viewing and editing the contents of HDF4 and HDF5 files. It allows users to browse through any HDF file, starting with a tree view of all top-level objects in an HDF file's hierarchy. HDFView allows a user to descend through the hierarchy and navigate among the file's data objects. Editing features allow a user to create, delete, and modify the value of HDF objects and attributes. For more info see:

http://www.hdfgroup.org/hdf-java-html/hdfview/

4.2.2 Panoply (free)

Panoply, developed at the Goddard Institute for Space Studies (GISS), is a cross-platform application which plots geo-gridded arrays from netCDF, HDF and GRIB dataset required. The tool allows one to slice and plot latitude-longitude, latitude-vertical, longitude-vertical, or time-latitude arrays from larger multidimensional variables, combine two arrays in one plot by differencing, summing or averaging, and change map projections. One may also access files remotely into the Panoply application.

http://www.giss.nasa.gov/tools/panoply/

4.2.3 H5_BROWSER (IDL/commercial)

The H5_BROWSER function presents a graphical user interface for viewing and reading HDF5 files. The browser provides a tree view of the HDF5 file or files, a data preview window, and an information window for the selected objects. The browser may be created as either a selection dialog with Open/Cancel buttons, or as a standalone browser that can import data to the IDL main program. You must purchase an IDL package, version 8 or higher to view the L2 HDF5 data files.

http://www.harrisgeospatial.com/ProductsandSolutions/GeospatialProducts/IDL.aspx

4.3 Programming Languages

Advanced users may wish to write their own software to read HDF5 data files. The following is a list of available HDF5 programming languages:

Free:

C/C++ (http://www.hdfgroup.org/HDF5/release/obtain5.html)

Fortran (http://www.hdfgroup.org/HDF5/release/obtain5.html)

Java (http://www.hdfgroup.org/hdf-java-html/)

Python (http://alfven.org/wp/hdf5-for-python/)

GrADS (http://www.iges.org/grads/)

Commercial:

IDL (http://www.harrisgeospatial.com/ProductsandSolutions/GeospatialProducts/IDL.aspx)

Matlab (http://www.mathworks.com/products/matlab/

5.0 Data Services

Access of GES DISC data now requires users to register with the NASA Earthdata Login system and to request authorization to “NASA GESDISC DATA ARCHIVE Data Access”. Please note that the data are still free of charge to the public.

5.1 GES DISC Search

The GES DISC provides a keyword, spatial, temporal and advanced (event) searches through its unified search and download interface:

https://disc.gsfc.nasa.gov/

The interface offers various download and subsetting options that suit the user’s needs with different preferences and different levels of technical skills. Users can start from any point where they may know little about a particular set of data, its location, size, format, etc., and quickly find what they need by just providing relevant keywords, such as a data product (e.g. “OMPS”), or a parameter such as “ozone”.

5.2 Direct Download

The OMPS data products may be downloaded in their native file format directly from the archive using https access at:

https://snpp-omps.gesdisc.eosdis.nasa.gov/data/

5.3 OPeNDAP

The Open Source Project for a Network Data Access Protocol (OPeNDAP) provides remote access to individual variables within datasets in a form usable by many OPeNDAP enabled tools, such as Panoply, IDL, Matlab, GrADS, IDV, McIDAS-V, and Ferret. Data may be subsetted dimensionally and downloaded in a netCDF4, ASCII or binary (DAP) format. The GES DISC offers the OMPS data products through OPeNDAP:

https://snpp-omps.gesdisc.eosdis.nasa.gov/opendap/

If you need assistance or wish to report a problem:
Email: gsfc-help-disc@lists.nasa.gov
Voice: 301-614-5224
Fax: 301-614-5268
Address:

6.0 More Information

Contact Information

Name:	GES DISC Help Desk
URL:	http://disc.gsfc.nasa.gov
E-mail:	gsfc-help-disc@lists.nasa.gov
Phone:	301-614-5224
Fax:	301-614-5228
Address:	Goddard Earth Sciences Data and Information Services Center Attn: Help Desk Code 610.2 NASA Goddard Space Flight Center Greenbelt, MD 20771 USA

Additional OMPS and ozone data products

http://ozoneaq.gsfc.nasa.gov

Suomi-NPP mission web page

http://jointmission.gsfc.nasa.gov/suomi.html

7.0 Acknowledgements

This project is funded in part by NASA award NNX14AR20A.

These data should be acknowledged by citing the product in publication reference sections as follows:

> Kai Yang (2017), OMPS-NPP L2 NM sulfur dioxide (SO_2) total column swath orbital V2.0, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), accessed ***[data access date]***, doi: 10.5067/A9O02ZH0J94R.

References

Dave, J. V. (1964), Meaning of successive iteration of the auxiliary equation of radiative transfer, Astrophys. J., 140, 1292–1303

Flynn, L., et al. (2014), Performance of the Ozone Mapping and Profiler Suite (OMPS) products, J. Geophys. Res. Atmos., 119, 6181–6195, doi:10.1002/ 2013JD020467.

Seftor, C. J., G. Jaross, M. Kowitt, M. Haken, J. Li, and L. E. Flynn (2014), Postlaunch performance of the Suomi National Polar-orbiting Part- nership Ozone Mapping and Profiler Suite (OMPS) nadir sensors, J. Geophys. Res. Atmos., 119, 4413–4428, doi:10.1002/2013JD020472.

McPeters, R. D., and G. J. Labow (2012), Climatology 2011: An MLS and sonde derived ozone climatology for satellite retrieval algorithms, J. Geophys. Res., 117, D10303, doi:10.1029/2011JD017006.

Spurr, R. J. D., J. de Haan, R. van Oss, and A. P. Vasilkov (2008), Discrete ordinate radiative transfer in a stratified medium with first order rotational Raman scattering, J. Quant. Spectrosc. Radiat. Transfer, 109(3), 404–425.

Vasilkov, A., J. Joiner, and C. Seftor (2014), First results from a rotational Raman scattering cloud algorithm applied to the Suomi National Polar-orbiting Partnership (NPP) Ozone Mapping and Profiler Suite (OMPS) Nadir Mapper, Atmos. Meas. Tech., 7, 2897–2906, doi:10.5194/amt-7-2897-2014.

Yang, K., N. A. Krotkov, A. J. Krueger, S. A. Carn, P. K. Bhartia, and P. F. Levelt (2007), Retrieval of large volcanic SO2 columns from the Aura Ozone Monitoring Instrument: Comparison and limitations, J. Geophys. Res., 112, D24S43, doi:10.1029/2007JD008825.

Yang, K., N. Krotkov, A. J. Krueger, S.A. Carn, P. K. Bhartia, and P. F. Levelt (2009a), Improving retrieval of volcanic sulfur dioxide from backscattered UV satellite observations, GRL, doi:10.1029/2008GL036036.

Yang, K., X. Liu, N. A. Krotkov, A. J. Krueger, and S. A. Carn (2009b), Estimating the Altitude of Volcanic Sulfur Dioxide Plumes from Space Borne Hyper-spectral UV Measurements, Geophys. Res. Lett., doi:10.1029/2009GL038025.

Yang, K. et al. (2010), Direct retrieval of sulfur dioxide amount and altitude from spaceborne hyper-spectral UV measurements: theory and application. JGR, doi:10.1029/2010JD013982.

Yang, K., R.R. Dickerson, S.A. Carn, C. Ge, and J. Wang (2013), First observations of SO2 from the satellite Suomi NPP OMPS: Widespread air pollution events over China, GRL., doi:10.1002/grl.50952.

Yang, K. et al (2014), Advancing measurements of tropospheric NO2 from space: New algorithm and first global results from OMPS, GRL., doi:10.1002/2014GL060136